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POTENTIAL APPLICATION OF SCATTEROMETRY TO LARGE-SCALE SOIL MOISTURE MONITORING

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1. INTRODUCTION

Mapping soil wetness or moisture on the large scale is important to the monitoring of global water cycle and its variability. Ku-band backscatter show a direct relation with seasonal land wetness distribution determined by water budget balance including precipitation, evaporation, runoff, and other components. To show the backscatter signature of seasonal hydrologic variations, we studied three strategic cases over the African continent and another case over Madagascar for approximately one year period from July 1999 to June 2000.

2. SEAWINDS SCATTEROMETER

The QuikSCAT satellite was successfully launched at 7:15 p.m. Pacific Daylight Time on 19 June 1999 from the Vandenberg Air Force Base in California. The satellite carries the SeaWinds scatterometer for ocean wind measurements [Graf et al., 1998]. The scatterometer has been collecting data at 13.4 GHz on both ocean and land. Backscatter data, at a radiometric resolution of 7 km x 25 km, are acquired with the vertical polarization σ_{VV} at a constant incidence angle of 54° over a conical-scanning swath of 1800 km, and with the horizontal polarization σ_{HH} at 46 ° over a 1400-km swath. The large swath can cover almost all the globe in 2 days even at low latitudes and equatorial regions. The satellite orbit was stabilized, the scatterometer performance was verified, and the calibrated science data have been obtained since 19 July 1999 [*Tsai et al.*, 2000].

3. RESULTS OVER THE AFRICAN CONTINENT

In this section, we present SeaWInds/QuikSCAT scatterometer signatures over various African regions where spatial distribution and seasonal evolution of soil moisture are different due to differences in regional climatic conditions. We show the correlation of time-series backscatter signature with in-situ measurements and results from scatterometer images over the African continent.

3.1. Central Africa

For central Africa, we selected Station Maradi in Niger. In Figure 1, backscatter measured by SeaWinds/QuikSCAT shows a general increasing trend from July to August 1999 with the peak in late August. Then the backscatter follows a decreasing trend from September 1999 to June 2000. The timing and trend of the backscatter seasonal variations compare well with station in-situ data as seen in Figure 1. Furthermore, transient short-term changes in backscatter show the correlation with precipitation events. Especially, rain events in June 2000 correspond to the backscatter responses at the same time.

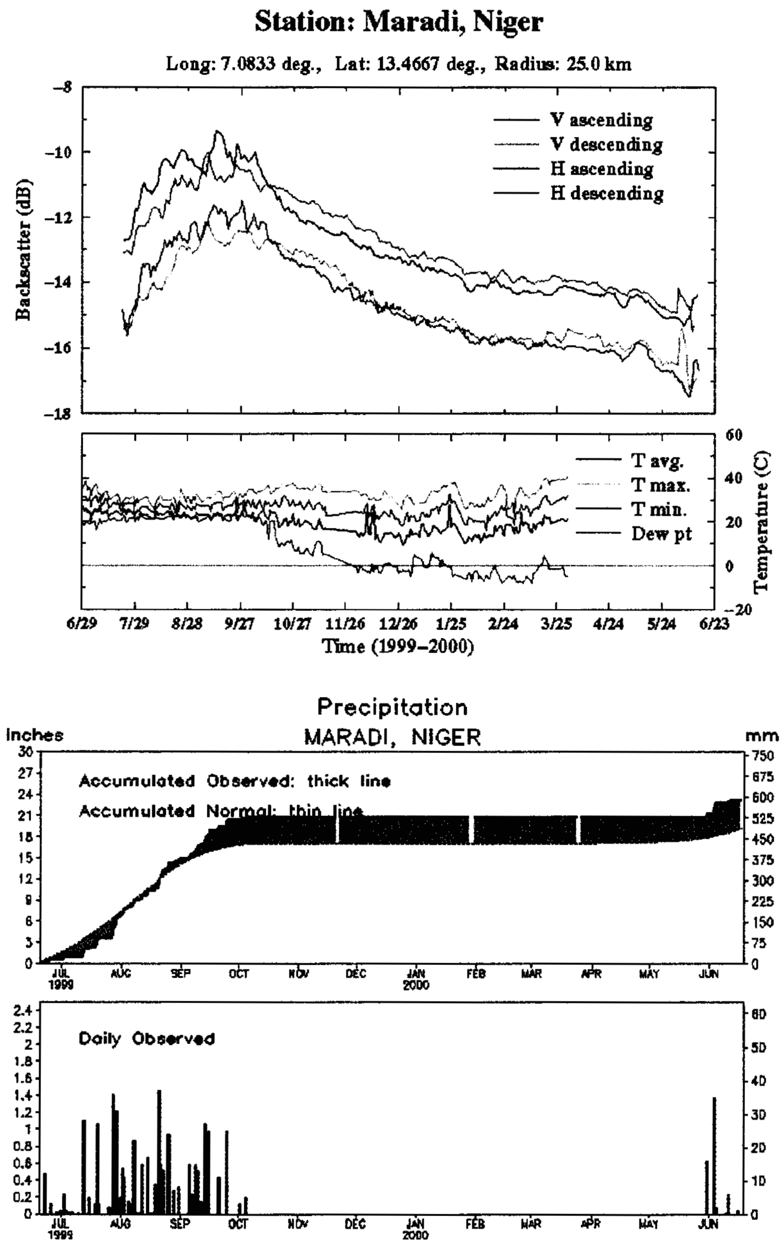

Figure 1: Time-series backscatter signature and in-situ data at Maradi, Niger

3.2. Southern Africa

For southern Africa, we investigated Station Pietersberg in South Africa. In contrast with the case of central Africa, backscatter in Figure 2 shows an unchanged low level from July to early October 1999 corresponding to the dry period as indicated by the precipitation data. In late October 1999, backscatter peak is observed in correlation with precipitation events as observed in Figure 2. Then the backscatter increases and maintains at a high level until February and March 2000 corresponding to the rain season there. After March 2000, the backscatter show some decreasing trend, which agrees with decreasing precipitation during the same time period. Again, transient short-time scale event such as that in early June is seen in both backscatter and precipitation data.

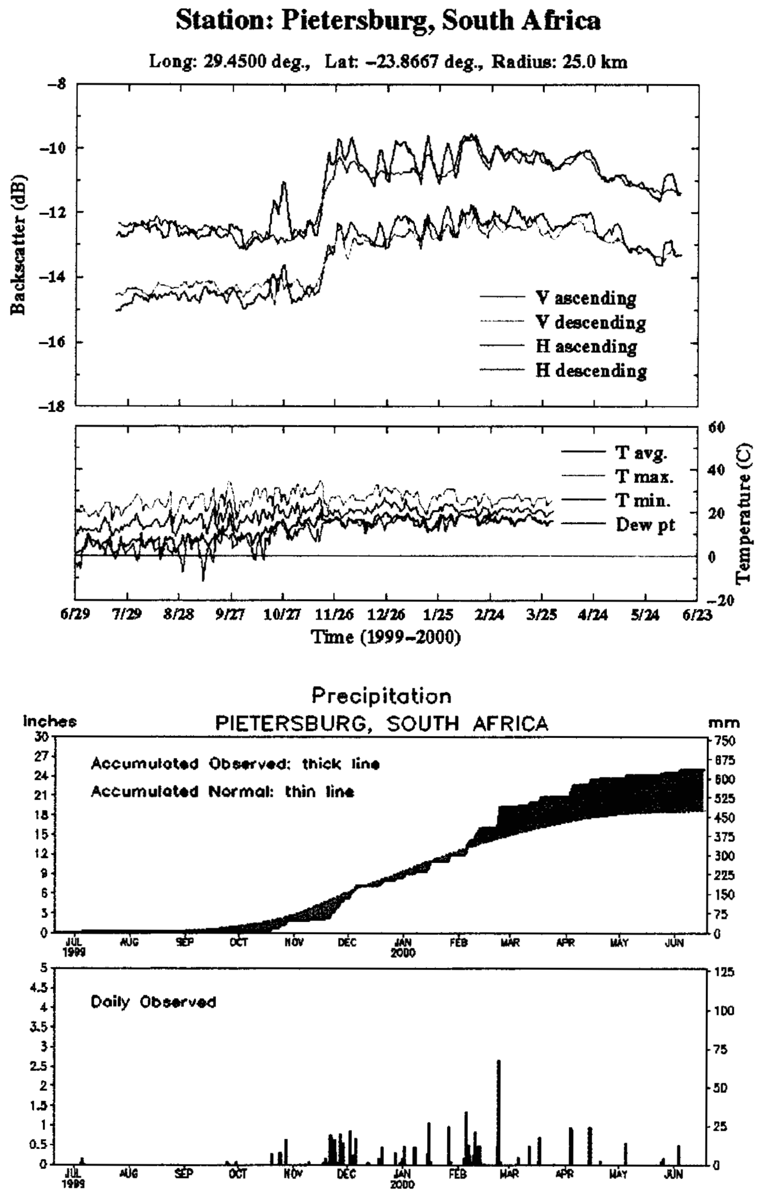

Figure 2: Time-series backscatter signature and in-situ data at Pietersburg, South Africa

3.3. Eastern Africa

For eastern Africa, we studied Station Gode in Ethiopia. As opposed to both of the above two cases, the backscatter signature in Figure 3 results at Gode show almost no change in backscatter corresponding to the dry condition as recorded in the station data throughout the time period under consideration as indicated in Figure 3. An isolated precipitation event in early October 1999, somehow, does not show up in the backscatter data. Some activities seem to occur during April-May 2000; however, station data are not available for that time period. Nevertheless, this case does confirm the constant backscatter response, which is consistent with the constant dry condition.

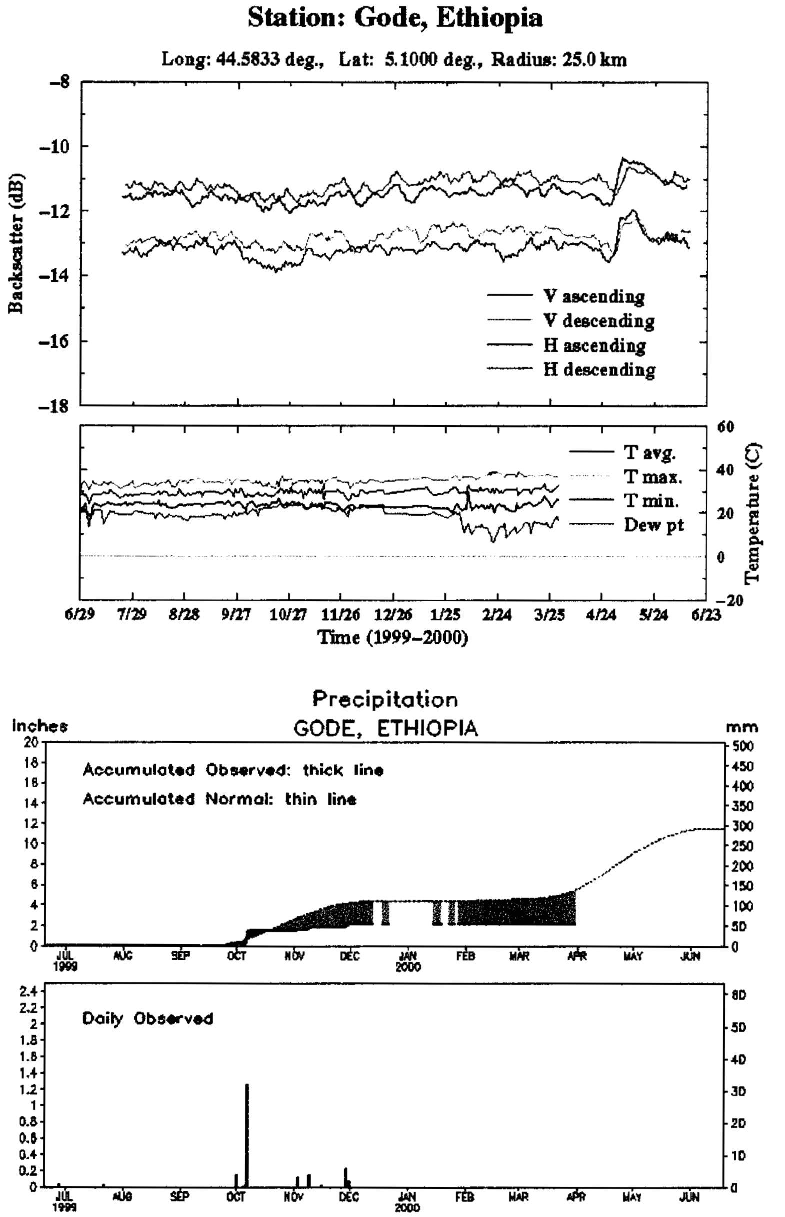

Figure 3: Time-series backscatter signature and in-situ data at Gode, Ethiopia

3.4. Madagacar

For Madagascar, we chose Station Antananarivo in the central region. Madagascar locates at about the same range of latitudes compared to South Africa and the seasonal moisture pattern in the internal region appears to be similar to that in South Africa. Time-series backscatter signature in Figure 4 reveals the initial increase in October 1999, a maximum level in early March, and a decreasing trend afterward. Over October-December 1999 in the early phase of the wet cycle, backscatter data show discrete time periods during which the backscatter was distinctively high in correlation with a spell of rain events as seen in Figure 4.

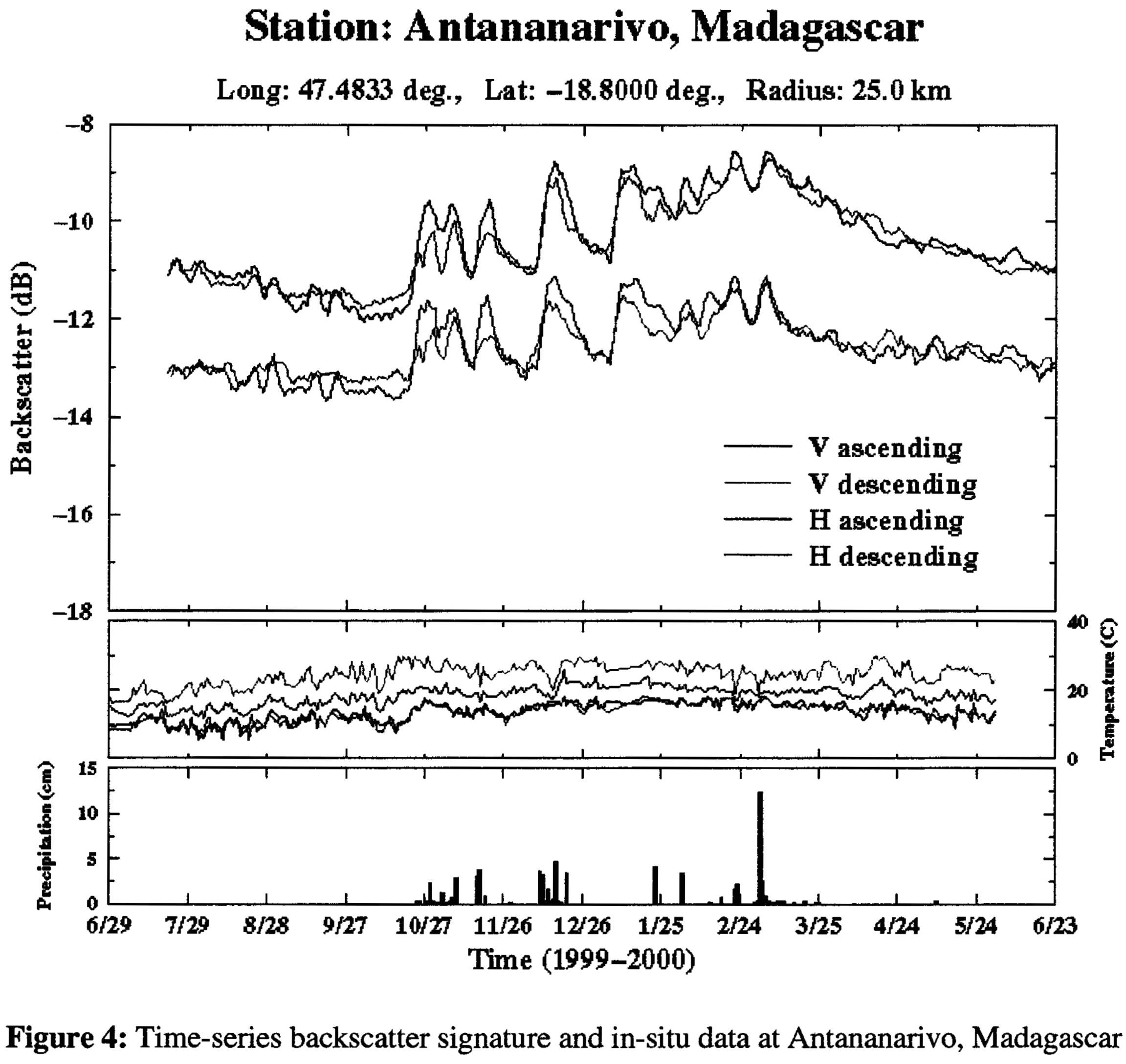

Figure 4: Time-series backscatter signature and in-situ data at Antananarivo, Madagascar

3.5. Spatial Patterns and Seasonal Evolution

SeaWinds/QuikSCAT images over the entire African continent show the spatial patterns and seasonal evolution of hydrological and ecological variations over the continent. Figure 5 presents two QuikSCAT image examples in July 1999 and in January 2000. The year-long results indicate: (1) the full cycle of the advancing and retreat over the middle region of the African continent corresponding to the annual moisture cycle over this region, (2) the expansion and shrinking of backscatter signature in southern Africa corresponding to the moisture cycle there, (3) the constant behavior in backscatter signature over the eastern African region of Ethiopia and Somalia, and (4) the annual cycle of backscatter signature in Madagacar with high backscatter invasion from the western coastal zone to the internal region and retreating back over the year-long time period corresponding to the seasonal evolution of the local precipitation pattern.

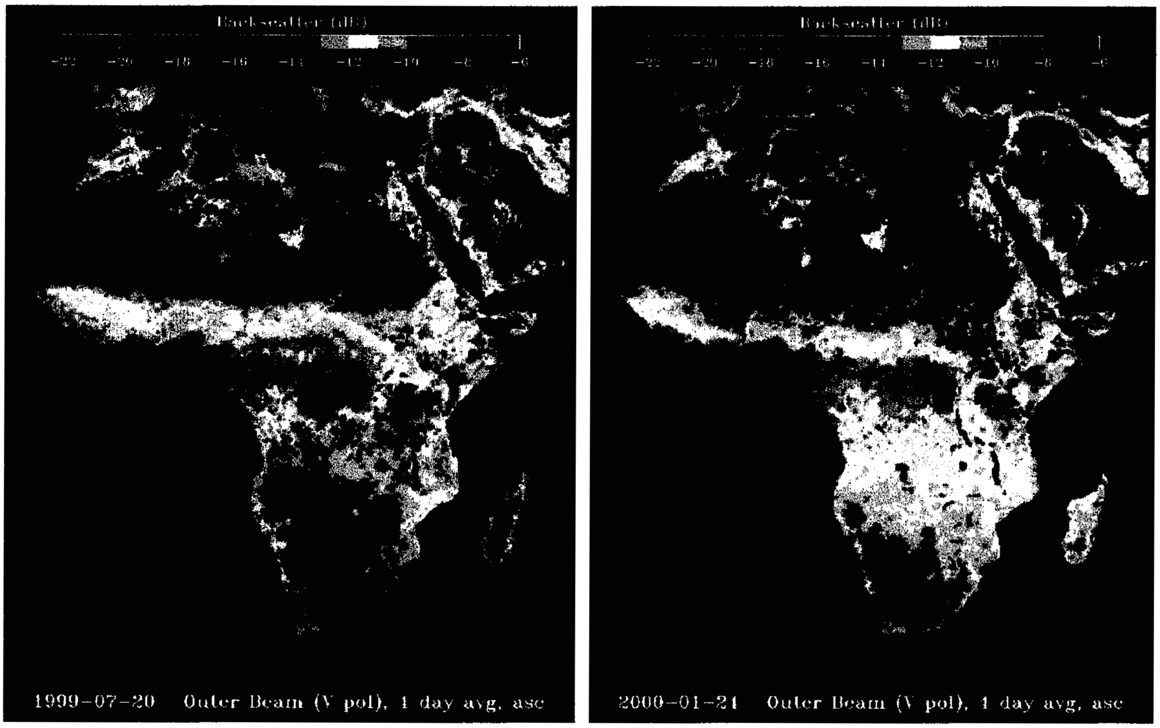

Figure 5: Backscatter signature over the African continent in July 1999 (left image) and January 2000 (right image) when the soil wetness distribution varied seasonally over different regions of Africa: The wetness was decreasing in the middle region, unchanged in the eastern region over Ethiopia, and increasing in the southern region and in Madagacar from 1999-07 to 2000-01. The seasonal change in the wetness distribution over Africa is observed with the correlated change in the scatterometer backscatter signature.

It is noted that the backscatter cycle in southern Africa is out of phase with the seasonal cycle in the middle due to the differences in precipitation pattern at different climatic regimes. Also, the Madagascar pattern varies synchronously with that in South Africa. Station data at Antananarivo show that the rain season started at about the same time as that at Pietersburg in South Africa, which provide a verification of the synchronous moisture pattern observed by QuikSCAT in the two different regions.

4. PHENOMENOLOGICAL MODEL AND ALGORITHM DEVELOPMENT

4.1. Phenomenological Model

Consider a phenomenological model for the total backscatter σ_0 consisting of the backscatter component σ_V for vegetation and another component σ_S for scattering mechanisms related wetness or moisture of soil under the vegetation:

$$\sigma_0 = \sigma_V + \sigma_S \tag{1}$$

The wavelength at 13.4 GHz (SeaWinds scatterometer operating frequency) is 2.2 cm. At such high frequency, a gap larger than the wavelength can allow the wave to go through. Except for dense tropical rain forest, many forest types have many large gaps (larger than 2.2 cm) in tree crowns and among different seperated trees. We describe the soil term σ_S with a gap model as

$$\sigma_S = [\gamma + \alpha(1-\gamma)]\,\sigma_{SS} \tag{2}$$

where γ represents the electromagnetic gap, $(1-\gamma)$ is the biomass fraction that affects the wave propagation by the attenuation factor α. Note that all parameters γ, α, and σ_{SS} are dependent on wave frequency. The frequency dependence of the attenuation factor α and backscatter σ_{SS} is obvious. For the gap γ, the frequency dependence can be understood by considering the case of a screen with holes or gaps of size *d*. If *d* is smaller than the wavelength, then most of the incident waves are reflected away. For *d* larger than the wavelength, the waves can go through the screen. Combining (1) and (2), we have

$$\sigma_0 = \sigma_V + [\gamma + \alpha(1-\gamma)]\,\sigma_{SS} \tag{3}$$

At Ku-band frequencies, there are several factors that support the gap model for the soil the moisture application related to the term σ_{SS}: (1) the short wavelength allows the waves to go through air gaps in vegetation cover, (2) σ_{SS} such as scattering for rough surface can become larger at higher frequency, and (3) σ_V becomes smaller relative to the other terms in (3). On the other hand, α is inversely related to frequency because a lower frequency has less attenuation through the vegetated material.

At Ku-band, Seawinds/QuikSCAT data show a continuous region with low backscatter without distinction across the distinctive boundary of taiga forest (large coniferous mixed with deciduous trees) and tundra region (mostly barren land with little vegetation) during summer (when the taiga vegetation is at peak growth conditions) over the northern region of the north American continent [*Nghiem et al.*, 2000]. This fact indicates that at Ku-band the effects of larger gaps, higher σ_{SS}, and relatively lower σ_V win over the effect of the higher attenuation. A gap model has also recently shown to be appropriate even at C-band frequency for forest penetration through gaps to allow the waves to probe through the vegetation cover [*Rodriguez et al.*, 2000].

4.2. Algorithm Development

We have shown the potential of using the scatterometer data for soil moisture applications. We are analyzing the data together with in-situ measurements to develop appropriate algorithms for soil moisture applications.

As seen from Figures 1-4, the backscatter signatures consist of the responses to both short-term meteorological events (rains) and climatic evolution over the season. We plan to develop an algorithm using spatial and temporal transformation such the wavelet or Fourier analyses to decompose the meteorological and climatic signatures. This will allow the investigation of the time-scale and spatial scale of the moisture distribution over Africa and other regions.

To determine geophysical parameters related to soil moisture or wetness, we plan to utilize global data sets of in-situ measurements by the global network of weather stations to develop empirical geophysical model functions relating backscatter to soil parameters. Such functions will allow the development of algorithms for parameter retrieval for applications to global soil moisture monitoring.

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